U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

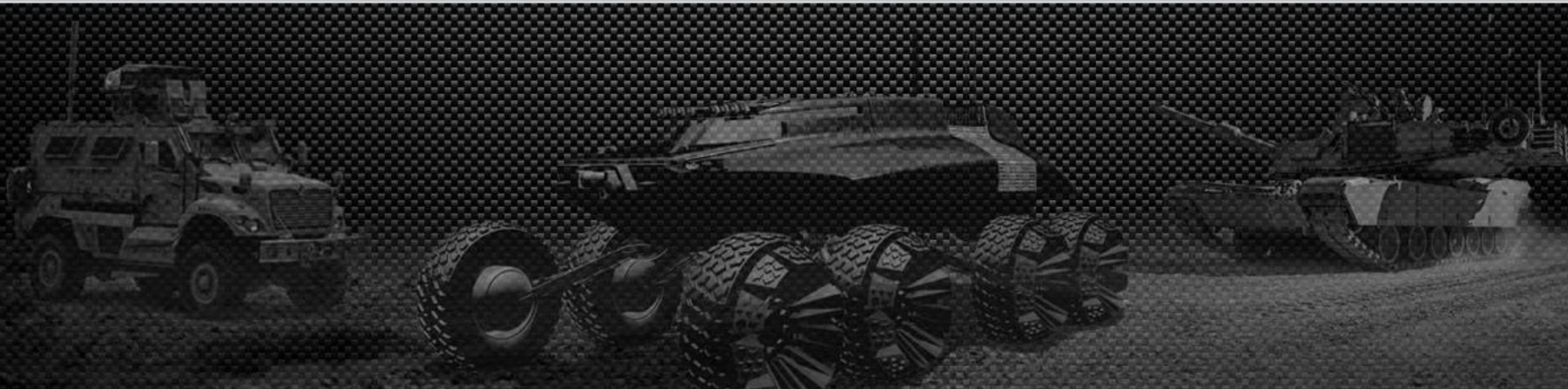
Fire Resistant Energy Attenuating Materials for use in Military Vehicles

Julie Klima

TARDEC Ground System Survivability

Interior Blast Mitigation Team

14 October 2015



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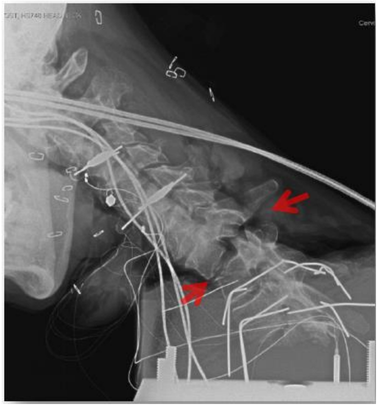
Problem Statement

- Statement of the Need
  - Underbody blast, collision and roll-over events in current military vehicles result in high percentage of head and neck impact related wounded and killed in action mounted war-fighters incapable of completing their mission.
  - Military ground vehicle interiors need significant improvement in mounted war-fighter head & neck impact protection over current vehicle performance

- Solution to the Need
  - Find an integrated solution for effective mounted war-fighter impact injury protection

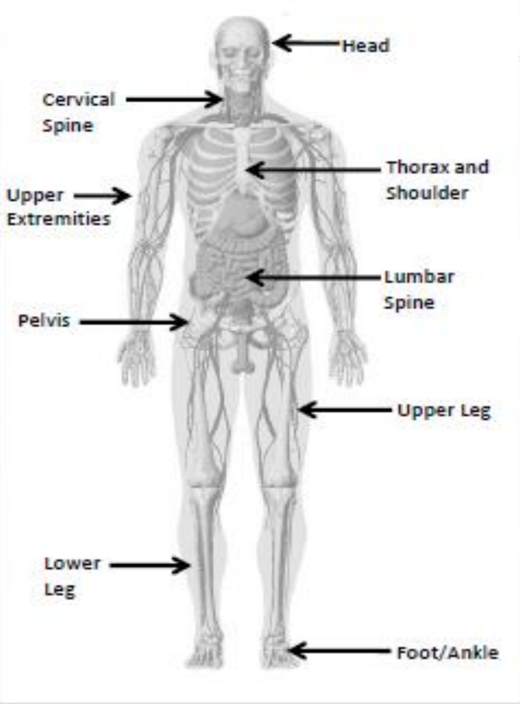


Injury Data

Medical Research and Materiel Command
U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama

Whole-Body Summary

KIA	Injuries (n=2180)	Indiv (m=116)
Head and Face	24%	84%
Cervical Spine and Neck	7%	52%
Upper Extremity	7%	49%
Torso (shoulder and abdomen)	35%	78%
Lumbar Spine	5%	30%
Pelvis (perineal and hip)	8%	51%
Lower Extremity	1%	9%
Upper Leg	4%	44%
Lower Leg (knee)	4%	43%
Foot/Ankle	7%	36%



WIA	Injuries (n=1664)	Indiv (m=439)
Head and Face	9%	16%
Cervical Spine and Neck	6%	19%
Upper Extremity	7%	16%
Torso (shoulder and abdomen)	20%	32%
Lumbar Spine	17%	35%
Pelvis (perineal and hip)	4%	8%
Lower Extremity	1%	2%
Upper Leg	2%	8%
Lower Leg (knee)	11%	28%
Foot/Ankle	23%	33%

n – total number of injuries for KIAs and WIAs, respectively
m – total number of individuals for KIAs and WIAs, respectively

February 1, 2012 40

Background - Vehicle Baseline Testing

- Testing the original structure of the vehicle without the addition of interior impact protective solutions, IIPS.
  - head impact injury performance of the vehicle's current design state
  - determines whether adding energy attenuating materials would be beneficial in reducing potential head impact injuries.

- Impact locations were selected based upon the proximity to the occupant's head in the upward and lateral motion typical of an underbody blast.

- Testing conducted at Soldier System Interface Impactor (SSII) Laboratory
  - Selfridge Air National Guard Base

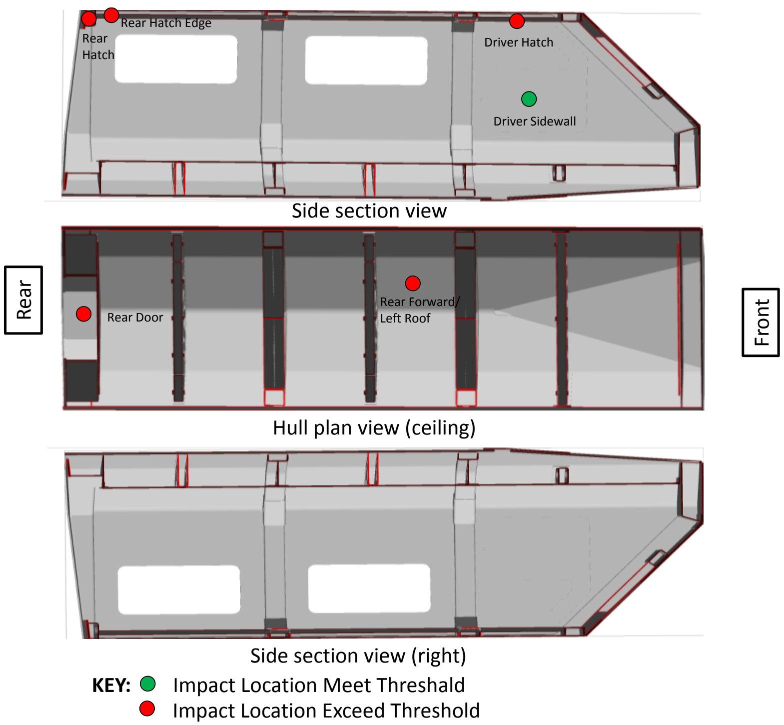
- Free Motion Headform (FMH) injury assessment values compared to Occupant Centric Protection (OCP)
  - Threshold: HIC(d) ≤ 1000
  - Objective: HIC(d) ≤ 700

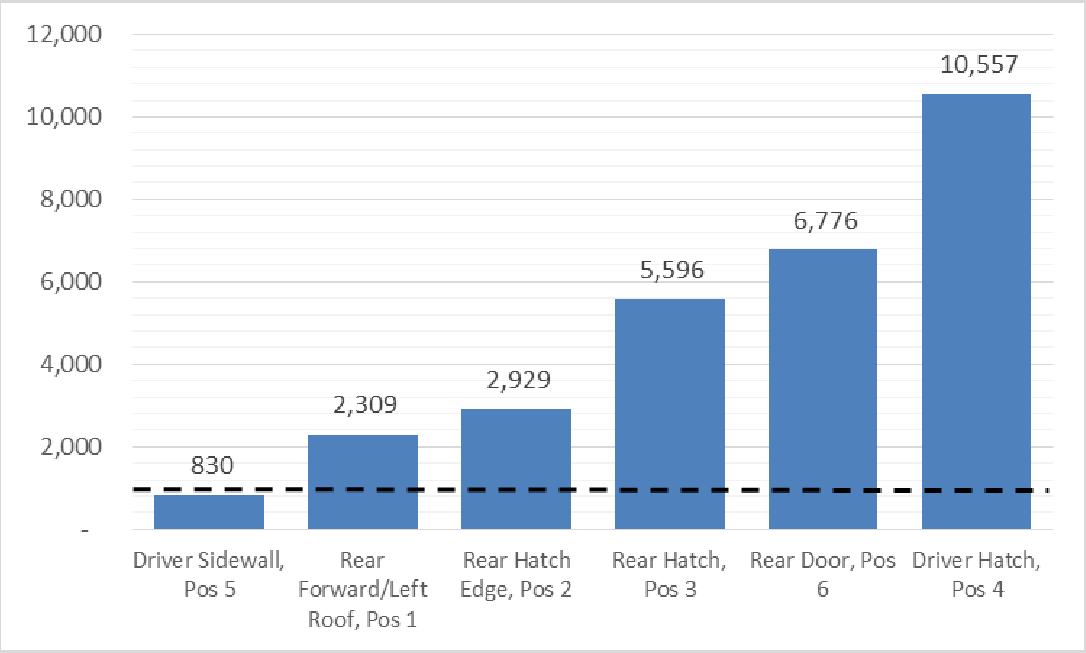
- FMH Impact Speed Measurement
  - 24 kph ± 1.0 kph

- Advanced Combat Helmet (ACH)
  - FMVSS 201U test equipment had too much variation for repeatability
  - Testing as conducted without an ACH where applicable

Vehicle A Baseline Testing

- 87 head impact tests performed from June 2013 to July 2013
- Baseline testing without ACH was conducted on 6 locations





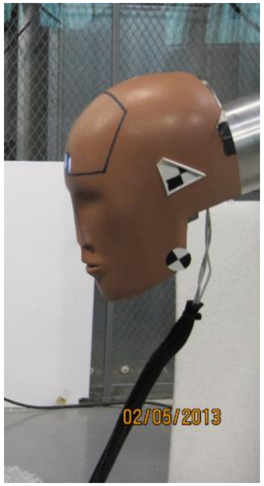
*Testing conducted without ACH

Data Takeaway:

- Very rigid interior design, significantly higher than the injury criteria requirements (HIC(d) < 1000)
- Threshold requirement met for 1 location
  - Driver Sidewall
- Driver sidewall location consists of an electrical door panel which may act as an energy attenuator providing enough energy dissipation to prevent impact related head injuries without needed additional protection.
- Next Steps:
  - Addition of EA materials to each baseline location.

Background – Material Testing

- Soldier System Interface Impactor (SSII) Laboratory located at Selfridge Air National Guard Base to conduct head impact testing
- FMH injury assessment values compared to Occupant Centric Protection (OCP)
  - Threshold: HIC(d) ≤ 1000
  - Objective: HIC(d) ≤ 700
- Current FMH analysis includes:
  - HIC(d) = 0.75446 (Free Motion Headform HIC) + 166.4
  - $\mathrm{HIC} = \left[\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2-t_1)$
- FMH Impact Speed Measurement
  - 24 kph ± 1.0 kph
- Advanced Combat Helmet (ACH)
  - FMVSS 201U test equipment had too much variation for repeatability
  - Testing as conducted without an ACH where applicable

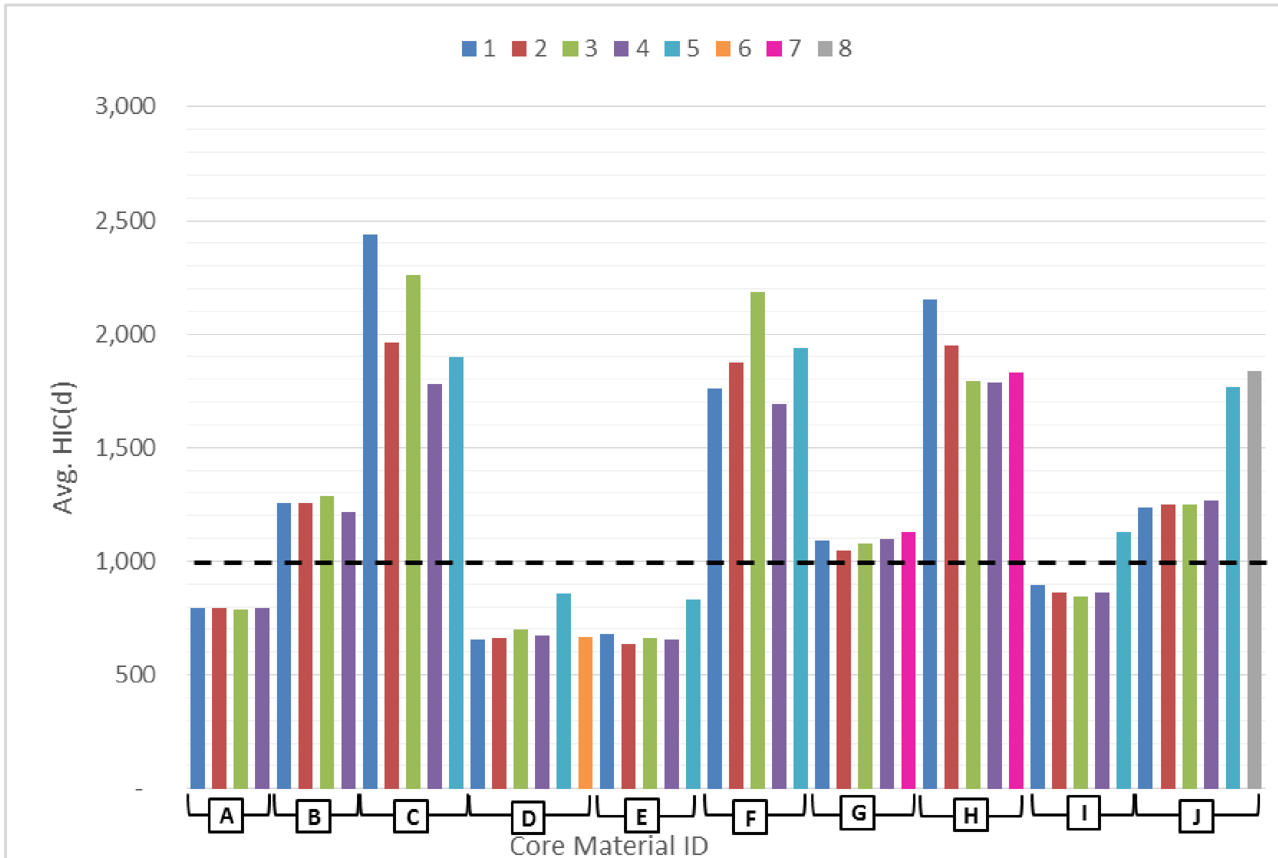


Material Analysis of Alternatives (AoA)

Core Material ID	Facesheet Material ID	Facesheet Material	Material	Thickness
A	1	Fabric	Plastic	1.4 inch (35.5 mm)
A	2	Fabric		
A	3	Fabric		
A	4	Fabric		
B	1	Fabric	Plastic	0.8 inch (20.3 mm)
B	2	Fabric		
B	3	Fabric		
B	4	Fabric		
C	1	Fabric	Plastic	0.5 inch (12.7 mm)
C	2	Fabric		
C	3	Fabric		
C	4	Fabric		
C	5	Rigid		
D	1	Fabric	Plastic	1.5 inch (38.1 mm)
D	2	Fabric		
D	3	Fabric		
D	4	Fabric		
D	5	Rigid		
D	6	Fabric		
E	1	Fabric	Plastic	1.5 inch (38.1 mm)
E	2	Fabric		
E	3	Fabric		
E	4	Fabric		
E	5	Rigid		
F	1	Fabric	Plastic	0.5 inch (12.7 mm)
F	2	Fabric		
F	3	Fabric		
F	4	Fabric		
F	5	Rigid		
G	1	Fabric	Foam	1.0 inch (25.4 mm)
G	2	Fabric		
G	3	Fabric		
G	4	Fabric		
G	7	Fabric		
H	1	Fabric	Foam	0.5 inch (12.7 mm)
H	2	Fabric		
H	3	Fabric		
H	4	Fabric		
H	7	Fabric		
I	1	Fabric	Non-resilent	1.6 inch (40.6 mm)
I	2	Fabric		
I	3	Fabric		
I	4	Fabric		
I	5	Rigid		
J	1	Fabric	Non-resilent	0.78 inch (19.8 mm)
J	2	Fabric		
J	3	Fabric		
J	4	Fabric		
J	5	Rigid		
J	8	Rigid		

- 150 head impact tests performed from January 2013 to May 2014
- Each core material was tested with a different durable exposed surface sheet to understand the effects the exposed surface sheet had on the energy attenuation characterizes of the core materials.

- Core material target thickness range: 25.4 mm (1.0 inch) to 38.1 mm(1.5 inch)
- Core material tested thickness range: 12.7 mm (0.5 inch) to 41 mm (1.6 inch)



Flame, Smoke, & Toxicity (FST) Methodology

- Current FST Standard: FMVSS 302
- TARDEC had very little data characterizing the thermal characteristics of the ignition sources typical to U.S. Army vehicles.
  - ignition time
  - heat generation
  - flame spread of the fire initiator
- Characterizing the fire initiator provides important information used to select appropriate fire assessment test methods.
- TARDEC developed fire resistance requirements based upon subject matter experts from NAVSEA and TARDEC's Fire Protection Team.
- NAVSEA conducted ASTM testing on selected material samples

Requirment	Objective	Test Method
Avg. Peak Heat Release Rate 50 kW/m2	< 85 kW/m^2	ASTM E1354
Peak Heat Release Rate after Ignition 50 kW/m2 @ 20 s, 180 s, & 300 s	< 60 kW/m^3	
Flame Spread Index	< 30	ASTM E162
Smoke Desity Flamming @ 240 s	Dm < 200	ASTM E662
Smoke Desity Non-Flamming @ 240 s		

IAV Fire

ASTM E1354 – Cone Calorimeter

- Heat Release Rate determined by measurement of oxygen consumption
  - determined by the oxygen concentration and the flow rate in the exhaust product stream
  - heat evolved from the specimen per unit of time
- $\dot{Q}(t) = \left(\frac{\Delta h_c}{r_o}\right)(1.10)C\sqrt{\frac{\Delta P}{T_e}}\frac{(X_{O_2}{}^{0} - X_{O_2}(t))}{1.105-1.5X_{O_2}(t)}.$

ASTM E1354 @ 300 seconds - Core Material G

Requirements	
Avg. Peak Release Rate	< 85 kW/m^2
Avg. Heat Release Rate @ 60 sec, 180 sec, & 300 sec	< 60 kW/m^2

		ASTM E1354 @ 50 kW/m^2			
		Avg. Peak Release Rate (kW/m^2)	Avg. Heat Release Rate @ 60 s	Avg. Heat Release Rate @ 180 s	Avg. Heat Release Rate @ 300 s
Core Material ID	B	1,019	117	394	NC
	G	415	260	342	277
	J	442	83	260	191
	L	675	142	413	317
	M	558	137	324	308
	N	376	168	221	215
	O	296	173	208	194
	P	82	49	36	NC
Facesheet Material ID	1	430	215	137	NC
	2	542	239	114	79
	3	693	311	180	NC
	4	771	371	210	NC
	5	462	146	208	NC

* NC = Not calculated; all flaming extinguished prior to this time point.

ASTM E162 – Surface Flammability of Materials

- Flame Spread Index (Radiant Panel Index)
  - Product of the flame spread factor, F, and the heat evolution factor, Q
  - If flame spreads from the pilot burner position to the first 3 inch park or from any 3 inch mark to the next in three seconds or less, is denotes with flashing

Core Material B Flaming ,Dripping, and Flashing at 60 sec

- TPE engineering polyurethane and polyethylene core materials
  - quickly ignited
  - exhibited rapid flame progression
  - flamed, dripped, and/or flame running

Requirements	
Flame Spread Index	< 30

		ASTM E162 @ 50 kW/m^2	
		Flame Spread Index	Flaming, Dripping, or Flame Running (Y/N)
Core Material ID	B	20	Yes
	G	1800	No
	J	123	No
	L	90	Yes
	M	116	Yes
	N	492	Yes
	O	309	Yes
	P	22	No
Facesheet Material ID	1	412	No
	2	582	Yes
	3	957	No
	4	1318	Yes
	5	158	No

ASTM E662 – Specific Optical Density of Smoke

Requirements	
Smoke Density Flaming @ 240 sec	$D_m < 200$
Smoke Density Non-Flaming @ 240 sec	$D_m < 200$

ASTM E662 @ 50 kW/m^2

		Flaming Mode		Non-Flaming Mode	
		Specific Optical Density (D_m)	Flaming, Dripping, or Flame Running (Y/N)	Specific Optical Density (D_m)	Flaming, Dripping, or Flame Running (Y/N)
Core Material ID	B	155	Y	6	N
	G	323	N	144	N
	J	16	N	1	N
	L	296	N	7	N
	M	300	Y	13	N
	N	582	N	320	N
	O	465	N	176	N
	P	23	N	6	N
Facesheet Material ID	1	106	N	154	N
	2	174	N	177	N
	3	187	N	185	N
	4	175	N	124	N
	5	196	N	28	N

- Optical Density: measurement characteristic of the concentration of smoke
- Specific optical density calculated at any given time:

$$D_s = G\left[\log_{10}\left(\frac{100}{T}\right) + F\right]$$

- Flaming mode
  - 6 tube burner is used to apply a row of flame across the lower edge of exposed specimen
  - Application of 6-tube burner and specified irradiance level from heating element
- Non-flaming mode
  - Specified irradiance level from heating element

ASTM E662 @ 178 seconds - Core Material O

Summary – Material FST Testing

		ASTM E1354 @ 50 kW/m^2				ASTM E162 @ 50 kW/m^2		ASTM E662 @ 50 kW/m^2			
								Flaming Mode		Non-Flaming Mode	
		Avg. Peak Release Rate (kW/m^2)	Avg. Heat Release Rate @ 60 s	Avg. Heat Release Rate @ 180 s	Avg. Heat Release Rate @ 300 s	Flame Spread Index	Flaming, Dripping, or Flame Running (Y/N)	Specific Optical Density (D_m)	Flaming, Dripping, or Flame Running (Y/N)	Specific Optical Density (D_m)	Flaming, Dripping, or Flame Running (Y/N)
Core Material ID	B	1,019	117	394	NC	20	Yes	155	Y	6	N
	G	415	260	342	277	1800	No	323	N	144	N
	J	442	83	260	191	123	No	16	N	1	N
	L	675	142	413	317	90	Yes	296	N	7	N
	M	558	137	324	308	116	Yes	300	Y	13	N
	N	376	168	221	215	492	Yes	582	N	320	N
	O	296	173	208	194	309	Yes	465	N	176	N
	P	82	49	36	NC	22	No	23	N	6	N
Facesheet Material ID	1	430	215	137	NC	412	No	106	N	154	N
	2	542	239	114	79	582	Yes	174	N	177	N
	3	693	311	180	NC	957	No	187	N	185	N
	4	771	371	210	NC	1318	Yes	175	N	124	N
	5	462	146	208	NC	158	No	196	N	28	N

* NC = Not calculated; all flaming extinguished prior to this time point.

Conclusion

- TARDEC identified a limited number of core and facesheet materials which are capable of complying with the fire resistance requirements

- TARDEC acknowledges these test methods and criteria may be more severe than needed, however some materials were determined to be capable of complying with these requirements, making it a viable option. On-going research and development efforts continue.

- TARDEC is further characterizing fire ignition sources and fire resistance standards with the intent to refine these requirements as more knowledge is gained.

- MIL-PRF-32518 Performance Specification Interior Head Impact Protection for us in U.S. Army Military Vehicle Interiors

Future Work

- TARDEC wishes to expand the number of materials known to provide sufficient energy attenuation, are capable of complying with the HIC(d) < 700 requirement and also provide adequate fire resistance
  - Phase II SBIR Flame, Smoke, and Toxicity Resistant Recoverable Interior Trim Energy Absorption Material
- Collaboration with FAA in FY16 for further development of fire resistance requirements for version 2 of MIL-PRF-32518